IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

AN ELECTRON LINEAR ACCELERATOR HAVING AN IDEAL BEAM LOADING CHARACTERISTIC

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Abstract

An electron linac with a traveling wave resonator in which the coupling is adjustable is presented. This linac has an ideal beam loading characteristic. When the beam current changes and so long as the coupler is adjusted to the optimal coupling its efficiency can maintain optimum. So its beam loading characteristic is a curve instead of a straight line. The curve has a steep slope in the range of small beam currents and has a slight slope in the range of large beam currents. This means that when the beam loading is light the energy of the electrons can rapidly increase with the beam loading decreasing; when the beam loading is heavy the energy will slowly descend with the beam current increasing.

1. Beam loading characteristic of a linac

For a constant impedance accelerator structure the energy gain of electrons is as follows

$$V = E_0 L \frac{1-e^{-\tau}}{\tau} - irL\left(1 - \frac{1-e^{-\tau}}{\tau}\right) \qquad (1)$$

To correspond with following formulae we rewrite eq.(1)

$$\left.\begin{aligned} V_1 &= M_1 E_0 L \frac{1-e^{-\tau}}{\tau} - irL\left(1 - \frac{1-e^{-\tau}}{\tau}\right) \\ M_1 &= 1 \\ C_1 &= 1 \end{aligned}\right\} \qquad (2)$$

Where M is the field multiplication factor, C the voltage coupling coefficient. The subscipts of V, M and C express different types of accelerators. The sketch of the linac with direct feed is in fig.1.

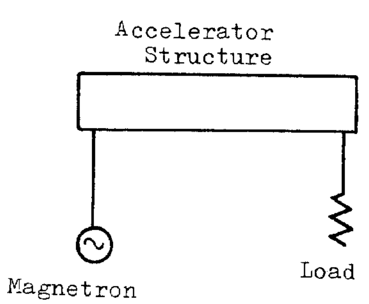

Fig.1

Its beam loading characteristic is a straight line. The slope of the line depends on the parameters of the accelerator structure. The line has a slight slope for the lower value of τ and the slope gets steeper and steeper with the value of τ increasing. They are shown in fig.2.

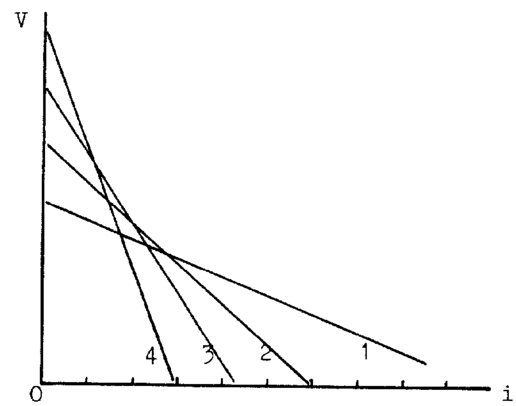

Fig.2

For a fixed accelerator length τ is a strong function of the aperture diameter of the loading disk in the accelerator structure. For a large diameter of the disk aperture (i.e. a small value of τ), the linac can accelerate large beam current, but the energy gain is lower. For a small diameter (i,e. a large value of τ), the linac has high energy gain, but can only accelerate small beam current.

2. Beam loading characteristic of a linac with feedback

A linac with feedback consists of an accelerator structure which has a low value of τ and a feedback loop which is coupled with the main waveguide by a 3db directional coupler (called as a bridge). Its sketch is shown in fig.3.

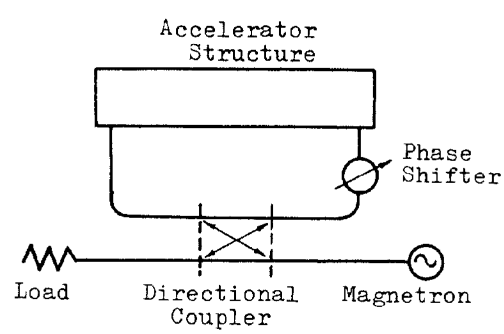

Fig.3

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Its energy gain is as follows:

$$\left.\begin{aligned} V_2 &= M_2 E_0 L \frac{1-e^{-\tau}}{\tau} - irL\left(1 - \frac{1-e^{-\tau}}{\tau}\right) \\ M_2 &= \frac{C_2 - \sqrt{1-C_2^2}\, ir(1-e^{-\tau})e^{-\tau'}/E_0}{1 - \sqrt{1-C_2^2}\, e^{-(\tau+\tau')}} \\ C_2 &= 0.707 \end{aligned}\right\} \quad (3)$$

We can find that the accelerator structure with the low value of τ and with direct feed i.e. C=1) has a slight slope of beam loading characteristic (line 1 in fig.4), but it with feedback (i.e. C=0.707) has a steep slope (line 2 in fig.4).

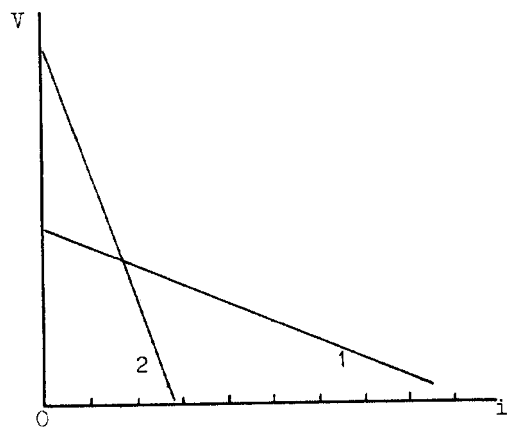

Fig.4

3. Ideal beam loading characteristic

From section 2 we can see that an accelerator structure with different coupling can has different beam loading characteristic. If we use a variable directional coupler, we can change its coupling to make the beam loading characteristic optimum when the beam current is different. Its sketch is shown in fig.5.

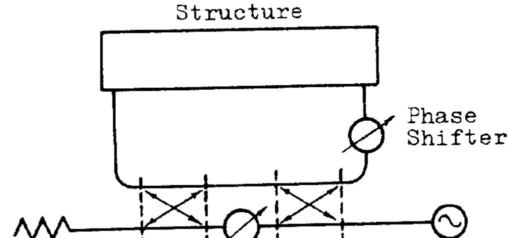

Fig.5

The optimal condition is available as long as we change coupling to make no power transmitted to the load for a variety of beam currents. It is the optimal coupling condition. It is the optimal efficiency condition too[1,2]. In this case , its energy gain is as follows:

$$\left.\begin{aligned} V3 &= M_3 E_0 L \frac{1-e^{-\tau}}{\tau} - irL\left(1 - \frac{1-e^{-\tau}}{\tau}\right) \\ M_3 &= \frac{\sqrt{i^2 r^2 (1-e^{-\tau})^2 e^{-2\tau'}/E_0 + (1-e^{-2(\tau+\tau')})}}{1-e^{-2(\tau+\tau')}} \\ &\quad - \frac{ire^{-(\tau+\tau')}e^{-\tau'}/E_0}{1-e^{-2(\tau+\tau')}} \\ C_3 &= 1/M_3 \end{aligned}\right\} \quad (4)$$

Its beam loading characteristic is shown in fig.6. It is a ideal beam loading characteristic. This means that when the beam current is small the energy gain of electrons can rapidly arise with the beam loading decreasing; when the beam current is large it will slowly descend with the beam loading increasing.

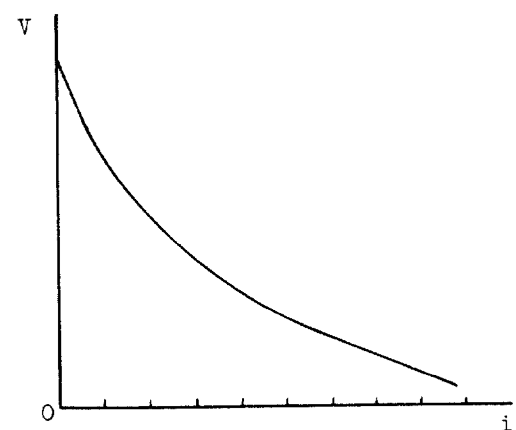

Fig.6

4. Comparison

In order to compare, we can constructe three linacs adopted the same accelerator structures which have lower value of τ :

(1). The linac with the direct feed (i.e. C=1).

(2). The linac with the feedback (i.e. C=0.707).

(3). The linac with traveling wave resonator under optimal coupling (i.e. C=1/M).

Their beam loading characteristics, field multiplication factors and coupling coefficients are shown in fig.7, fig.8 and fig.9 respectively.

We can see that the parameters of the third type of linac are values of optimal transition from thr first type to the second type.

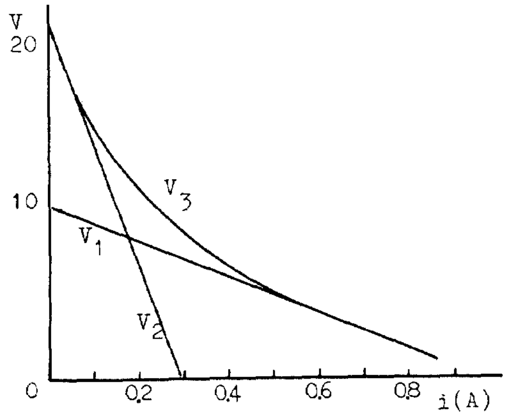

Fig.7

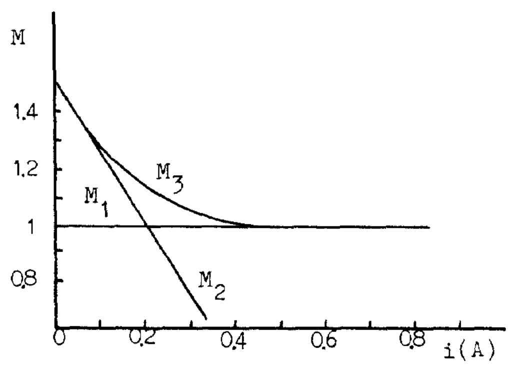

Fig.8

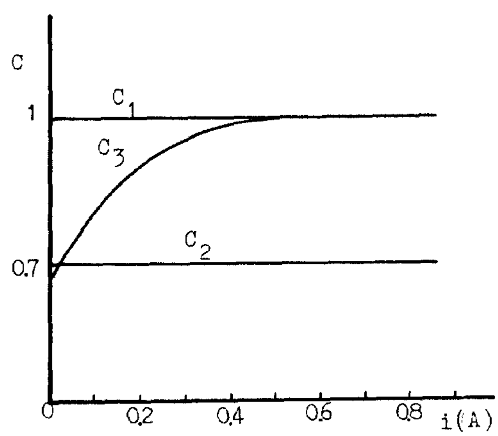

Fig.9

5. Our linac

In order for our university to constructe a linac we design the linac with traveling wave resonator under optimal coupling condition. A 5MW magnetron is used as a power source. The length of the accelerator structure is 2.5m. The attenuation of the accelerator structure is 0.21 nepers. The variable directional coupler consists of two 3db directional couplers and a phase shifter. When the phase of the shifter changes from 0 to π the coupling will change from C=0 to C=1. The parameters of beam currents and electrons energy are as follows:

Current (mA)	10	60	150	300	500	800
Energy (Mev)	20	17.5	14.4	10.5	7.2	3.5

To avoid appearing BBU we will make two holes in some diaphragms of the accelerator structure (fig.10) and increase the magnetic field for the focus.[3]

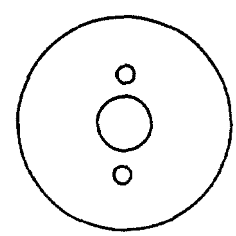

Fig.10

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3. Yao Chongguo, IEEE Trans. Nucl. Sci. Vol. NS- 32 No.4 1985